CP value of K_S^0 and K_L^0 pair

Weiping Wang

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The CP properties of strange mesons

$$J^P(K^+) = J^P(K^-) = 0^-$$
$$J^P(K^0) = J^P(\bar{K}^0) = 0^-$$

Since K_S^0 mainly decays to $\pi\pi$ final states, and both $\pi^+\pi^-$ and $\pi^0\pi^0$ are positive CP systems, we find that

$$\eta_{CP}(K_S^0) = +1.$$

While $3\pi^0$ is the dominant final state of K_L^0 and the $3\pi^0$ is the negative CP system, then

$$\eta_{CP}(K_L^0) = -1.$$

The CP properties of strange mesons pair

$$\hat{C}\hat{P}\left|K^+K^-\right\rangle = (-1)^{L_0}(-1)^{L_0+S}\left|K^+K^-\right\rangle = +1\left|K^+K^-\right\rangle$$

$$\hat{C}\hat{P}\left|K^0\bar{K}^0\right\rangle = (-1)^{L_0}(-1)^{L_0+S}\left|K^0\bar{K}^0\right\rangle = +1\left|K^0\bar{K}^0\right\rangle$$

where L_0 and S is the relative angular momentum and spin of $K\bar{K}$ system. Therefore, we conclude that

$$\eta_{CP}(K^+K^-) = \eta_{CP}(K^0\bar{K}^0) = +1.$$

The $\left|K^0\bar{K}^0\right\rangle$ can further transit to $\left|K_S^0K_L^0\right\rangle$, $\left|K_S^0K_S^0\right\rangle$, and $\left|K_L^0K_L^0\right\rangle$, respectively. Their CP values take the form

$$\eta_{CP}(K_S^0K_L^0) = \eta_{CP}(K_S^0)\eta_{CP}(K_L^0)(-1)^{L_0^a} = (-1)^{L_0^a+1}$$

$$\eta_{CP}(K_L^0K_L^0) = \eta_{CP}(K_S^0K_S^0) = \eta_{CP}(K_S^0)\eta_{CP}(K_S^0)(-1)^{L_0^b} = (-1)^{L_0^b}$$

where L_0^a and L_0^b are the relative angular momentum of corresponding system.

The CP properties of strange mesons pair

Note that the $|K_S^0 K_L^0\rangle$, $|K_S^0 K_S^0\rangle$, and $|K_L^0 K_L^0\rangle$ are originating from the $|K^0 \bar{K}^0\rangle$, therefore

$$\eta_{CP}(K_S^0 K_L^0) = \eta_{CP}(K_L^0 K_L^0) = \eta_{CP}(K_S^0 K_S^0) = \eta_{CP}(K^0 \bar{K}^0) = +1.$$

This leads that

$$L_0^a = 2n + 1, \text{ and } L_0^b = 2n \; (n = 0, 1, 2, \cdots).$$

Also, $L_0^b = 2n$ is the requirement of identical particle system.

The $e^+e^- \to K_S^0K_S^0$(or $K_L^0K_L^0$) is not allowed

In the process $e^+e^- \to K^0\bar{K}^0$

$$\vec{J}(K^0\bar{K}^0) = \vec{L}_0 + \vec{S} = \vec{L}_0$$

$$\eta_C(K^0\bar{K}^0) = (-1)^{L_0+S} = (-1)^{L_0}$$

$$\eta_P(K^0\bar{K}^0) = (-1)^{L_0}$$

where L_0 and S is the relative angular momentum and total spin of $K\bar{K}$ system. While for the initial state

$$\vec{J}(e^+e^-) = \vec{J}(\gamma) = \vec{1}$$

$$\eta_C(e^+e^-) = \eta_C(\gamma) = -1$$

$$\eta_P(e^+e^-) = \eta_P(\gamma) = -1$$

Thus, in this process

$$L_0 \equiv 1.$$

Therefore only the process $e^+e^- \to K_S^0K_L^0$ is allowed.

The $e^+e^- \to K^0_S K^0_L J/\psi$ is not allowed

In the process $e^+e^- \to K^0\bar{K}^0 J/\psi$

$$\vec{J}(K^0\bar{K}^0) = \vec{L_0} + \vec{S} = \vec{L_0}$$

$$\eta_C(K^0\bar{K}^0) = (-1)^{L_0+S} = (-1)^{L_0}$$

$$\eta_P(K^0\bar{K}^0) = (-1)^{L_0}$$

where L_0 and S is the relative angular momentum and total spin of $K\bar{K}$ system. When take the J/ψ into consideration

$$\vec{J}(K^0\bar{K}^0 J/\psi) = \vec{J}((K^0\bar{K}^0)J/\psi) = (\vec{L_0} + \vec{1}) + \vec{L_1}$$

$$\eta_C(K^0\bar{K}^0 J/\psi) = \eta_C(K^0\bar{K}^0)\eta_C(J/\psi) = (-1)^{L_0+1}$$

$$\eta_P(K^0\bar{K}^0 J/\psi) = \eta_P(K^0\bar{K}^0)\eta_C(J/\psi)(-1)^{L_1} = (-1)^{L_0+1+L_1}$$

where the L_1 is the relative angular momentum between $K^0\bar{K}^0$ and the J/ψ.

The $e^+e^- \to K^0_S K^0_L J/\psi$ is not allowed

Comparing to the initial states

$$\vec{J}(e^+e^-) = \vec{J}(\gamma) = \vec{1}$$

$$\eta_C(e^+e^-) = \eta_C(\gamma) = -1$$

$$\eta_P(e^+e^-) = \eta_P(\gamma) = -1$$

We find that

$$L_1 \equiv 0, 2$$

and

$$L_0 \equiv 0$$

Therefore, the $e^+e^- \to K^0_S K^0_L J/\psi$ is not allowed.
In addition, according to the isospin symmetry, the cross section ratio between $e^+e^- \to K^0_S K^0_S J/\psi$ and $e^+e^- \to K^+K^- J/\psi$ processes is 1/2 (another 1/2 is originated from $e^+e^- \to K^0_L K^0_L J/\psi$).